

MEMO

TITLE

GEORGE MASSEY CROSSING IMMERSED TUBE
TUNNEL TECHNICAL SUMMARY

DATE

29 November 2019 – DRAFT FOR REVIEW

TO

Darryl Matson, GMC Technical Lead

COPY

FROM

Tommy Olsen, GMC Immersed Tube Tunnel Lead
A127810

PROJECT NO

ADDRESS COWI North America Ltd.
138 13th Street East
Suite 400
North Vancouver
BC V7L 0E5
Canada

TEL +1 604 986 1222

WWW cowi.com

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1 Introduction

In July 2019, COWI North America Ltd. and Stantec (the COWI-Stantec Team [CST]) were awarded an assignment to provide as & when technical services to the BC Ministry of Transportation and Infrastructure (Ministry) for the George Massey Crossing Project. The assignment was to provide technical support in response to questions asked by the Ministry (or the Mayors Task Force through the Ministry). Importantly, CST was specifically not to provide recommendations.

A key question asked by the Ministry was: **what would a new Immersed Tube Tunnel (ITT) option look like at the crossing, and what would the project cost be if this technology is selected for the crossing?** This memorandum describes the work performed by CST to develop a conceptual design that would respond to this question.

Unlike the Bridge and Bored Tunnel options being considered, there have been very few ITT's built in North America, and each location has its own challenges that make it difficult to rely heavily on engineering judgement to develop with confidence a conceptual design. Therefore, CST performed more engineering developing the ITT concept than the Bridge or the Bored Tunnel concepts. As a result, this memorandum shows more detail than the memoranda for the other technologies. The concept design has been developed in sufficient detail to give confidence in its feasibility and that the cost estimate, programme, project risk, and environmental impact is within the same level of accuracy as the Bridge and Bored Tunnel options.

This memorandum presents a technical summary of the work that CST developed for both the 6-lane crossing and 8-lane ITT options. This memorandum also documents the assumptions made for the functional requirements that affect the design of the tunnel.

CST's work initially considered both a 6 lane and 8 lane ITT option. This memorandum presents some of the preliminary work performed regarding the 6 lane option, but, based on direction from the Ministry, mainly outlines the work completed on the 8 lane option. This memo covers tunnel and ramps structures, including Mechanical & Electrical (M&E) installations, from crest to crest of the north and south portals. The new crossing consists of an immersed tube tunnel under the river, immersed tunnels where the onshore excavations are deep and cut-and-cover and retaining wall structures on either end of the new immersed tunnel. Also included in this memo are typical bridge structures for the Deas Slough crossing and the River Road Overpass.

This conceptual design establishes ITT cross sections, dimensions, and quantities, based on the required clearance profiles and reasonable assumptions regarding material properties and requirements.

The conceptual design of the new ITT is based on experience gained from design and construction of international immersed tunnels (approximate 150 immersed tunnels worldwide since 1900), shared via the international immersed tunnel networks including the International Tunnelling Association, ITA.

Conceptual design drawings are included in Appendix A of this memorandum. Further detailed information is included in Appendix B of this memorandum. The conceptual design of the replacement Deas Slough bridge and the new River Road overpass required as part of the ITT project is presented in Appendix C of this memorandum.

2 Approach and Design Basis

The work has been completed during a short period of time. Conclusions are based on preliminary analysis, as well as experience from other ITT projects around the world. The work carried out presented in this memo is considered to be sufficiently detailed to cover key items, project risk and overall quantities to be used in a comparison with other technologies and to form the basis for a decision on technology for the George Massey Crossing.

2.1 Approach

The concept design for the new ITT focused on the following key items:

- > Type of immersed tunnel with 4-lane tubes in seismic conditions;
- > Fabrication of tunnel elements and the corresponding impact on the type of ITT;
- > Articulation of immersed tunnel under seismic events to avoid complex joints;
- > Environmental constraints for tunnel protection and construction;
- > Ground improvement to deal with the risk of soil liquefaction; and
- > Fire & life safety (FLS), ventilation, and mechanical and electrical (M&E) concepts to allow for sizing the cross section of the tunnel.

The key design basis and assumptions are presented in the following section.

2.2 General Design Basis

The following design basis were assumed for the conceptual design of the ITT options:

- > CST has assumed a design life for non-replaceable components of structures and foundations of 120 years. Design life for replaceable components such as M&E equipment, road wearing surface and finishing works will be determined at a later date based on a life-cycle cost assessment.
- > There is no design code for road tunnels in Canada, and therefore it is common practice in tunnel design to piece together design requirements

from other codes and standards. For this assignment, CST relied on the Canadian Highway Bridge Design Code (CHBDC) CAN/CSA-S6-14 (where applicable), including the BC Supplement and supplemented this with international guidelines and recommendation for design of road tunnels (World Road Association PIARC) and immersed tunnel (International Road Association ITA).

- > CST developed the highway alignment, which is shown on drawings IT901 and IT902 in Appendix A. The alignment is upstream of the existing tunnel.
- > The distance between the new and old tunnel alignments is governed by the requirements for underwater excavations. CST determined that under water, the sands of the Fraser River are stable at a 2H:1V (horizontal to vertical) slope, assuming some protection of the slope face is provided (geo bags or a thin concrete mat). In order to provide slightly more safety, the CST decided to use a 2.3H:1V slope for the downstream cut and 3H:1V slope for the upstream excavation. Using these slopes result in a clear distance of 42m between the edge of the existing tunnel and the edge of the new tunnel, which the team considers reasonable at this stage of design. Hydraulics of the river with the open cut were verified during the non-freshet construction windows, and found to be acceptable. Early concepts developed by CST included an underwater retaining wall on the downstream excavated slope, which resulted in a separation of only 25m, but this was determined to be excessively expensive and potentially extended the construction schedule by a year. As such, the underwater retaining wall option was abandoned.
- > The Ministry required that the 8 lane ITT include two multi-use paths (MUP): one on each side of the tunnel element. The design, and this memo, are based on 3.5m wide MUP's.
- > Tunnel safety is designed based on recommendations by the National Fire Protection Association (NFPA) for a Category D tunnel. Category D tunnels are defined by NFPA 502 as those where the tunnel length equals or exceeds 1,000m. It is understood that dangerous goods will be allowed to travel through the tunnel, and the FLS requirements outlined in this memo account for this.
- > The traffic clearance envelop was provided by the Ministry, and requires 5m vertical clearance for the traffic lanes, 3.7m wide General Purpose (GP) and Bus Only traffic lanes, 1m inside and outside shoulders for the 8 lane configuration, and 1m inside and 1.5m outside shoulders for the 6 lane configuration. Appendix B of this memorandum gives more detail of the Concept Design for the 8 lane option.
- > Rip rap protection is required around the new tunnel to prevent scour, and it has been tied into the rip rap of the existing tunnel to prevent scour between the two tunnels.
- > CST developed geotechnical input for the Concept Design including geological information, soil properties, and seismic considerations.

- > The ITT shall be designed as a "Lifeline" structure. Based on CHBDC, this requires that the structure be designed against loss of structural integrity with 2% likelihood over 50 year (seismic events with a return period of 2475 years). The seismic conditions, such as peak ground accelerations and firm ground (Class C) time histories for different return periods, were developed by CST and were used for the Concept Design.
- > The assumed navigation channel is shown on drawing IT902, and corresponds to a width of 325m and a depth of Elevation -15m (Geodetic), centred on the river. The width is based on requirements for the previous tender design for the George Massey Replacement Project, and includes the two way channel and the indicative nautical clearance safety zones. The previous studies/bids for the replacement of the George Massey Tunnel have not provided an underwater clearance envelop. Since this affects the depth of the new ITT, and since there was not sufficient time to liaise with the necessary agencies to determine the clearance requirements, CST assumed that the underwater clearance requirements will be similar but slightly deeper than those established recently for the upstream Pattullo Bridge.
- > CST has assumed that the railway on the north side of the River, and Rice Mill Road can be temporarily re-routed during construction.

3 Immersed Tunnel Cross-Sections

The cross-sections for the concept design of the 6 lane and 8 lane options are shown below. Further details are provided for the 8 lane option.

3.1 Four Tube Cross-Section – 6 Lane Option

The cross section of the six lane option comprises of two three lane road tubes and two 3.5 m wide MUP tubes.

Horizontal and vertical clearance requirements are shown in Figure 1. Fire protection or installation tolerances have not been added to the clearance requirements.

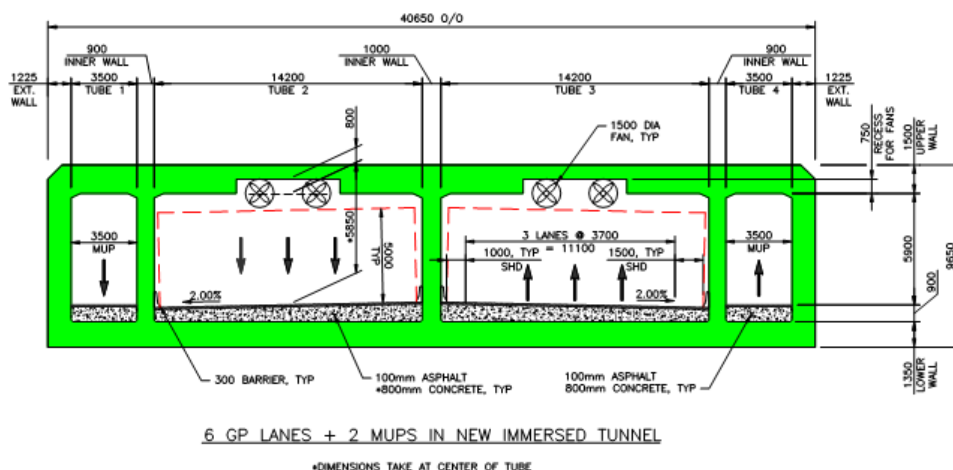


Figure 1: Clearance requirements and typical cross-sections for 6 lane option ITT (dimensions in mm)

3.2 Four Tube Cross-Section – 8 Lane Option

The cross section for the 8 lane option comprises of two four lane road tubes and two 3.5 m wide MUP tubes.

Assumed requirements to horizontal and vertical clearance are shown in Figure 2. Fire protection or installation tolerances have not been added to the clearance requirements.

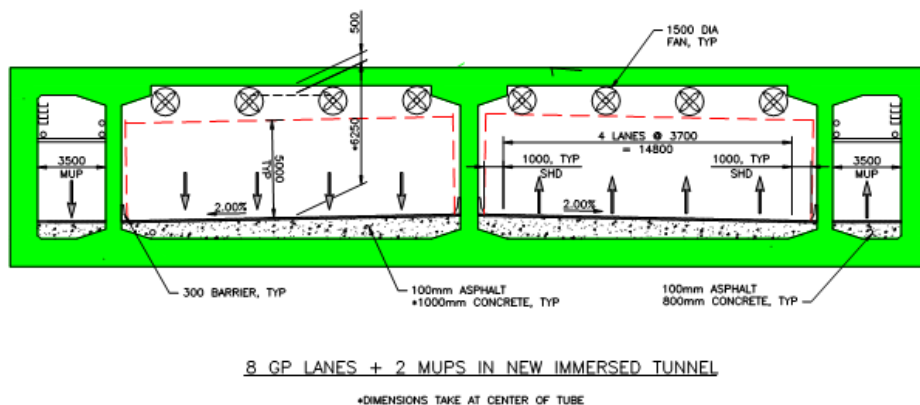


Figure 2: Clearance requirements and typical cross-sections for 8 lane option ITT (dimensions in mm)

Due to the relatively large width of the road tubes in the 8 lane option, CST investigated two different design options for the section:

- > Type 1 - Concrete section with post tensioning in top and bottom slabs and the outer walls; and
- > Type 2 - Steel – Concrete – Steel, sandwich type (SCS-type) section.

These options are shown in Figure 3

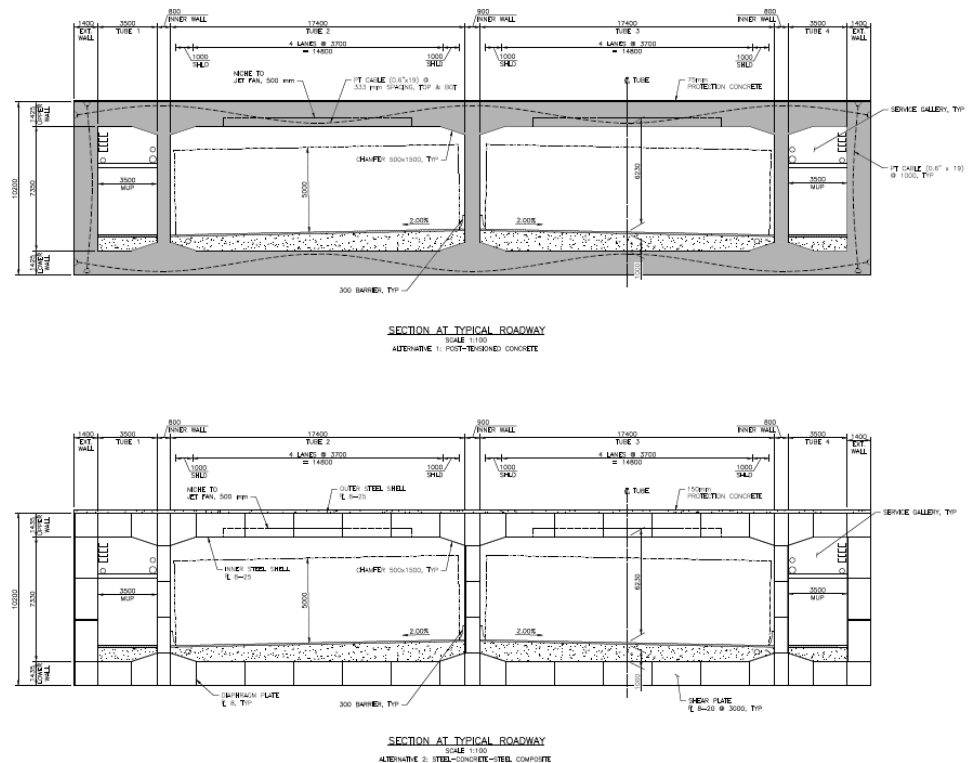


Figure 3: Two possible section types for the 8 lane ITT option (dimensions in mm)

4 Foundations and Tunnel Protection Layout

4.1 Foundations and Foundation Layer

Preliminary assessment of the geotechnical profile and deformation properties of the soil indicates that the static settlements will be relatively low. The geotechnical profile also indicates relatively "uniform stratigraphy" across the river channel and under the north and south ramp structures, hence it is assumed that the risk of differential settlements leading to excessive joint movements and longitudinal forces in the structure will be manageable under normal conditions.

In terms of consolidation settlements, the ground consists primarily of relatively permeable materials in the upper approximate 25m of sandy soils. CST estimated the long-term consolidation settlements in the lower silty and clayey soil layers to be 100 mm which is acceptable for the immersed tunnel structure and the majority of the consolidation settlements are categorized as re-consolidation settlements following the dredging and excavation operations. Therefore, vertical settlements of the tunnel elements mostly occur before the elements are structurally connected.

For the immediate ground settlements caused by placing locking fill and backfill, it will be necessary to control the settlements by an engineered backfilling

process to ensure that differential settlements across the joints, due to differences in loadings from backfill between the elements, will be within acceptable limits.

The soil below the ground water table is generally exposed to the risk of liquefaction. For the new tunnel and ramp structures, ground improvement is required in the native soils which have been identified as liquefiable sandy soils and are generally present under and on both sides of the tunnel. Liquefaction related seismic hazards include potential tunnel flotation, post-earthquake longitudinal differential settlements, and riverbank flow slides. Seismic actions are expected not to be governing transverse design. Adequate ground improvement would mitigate these hazards and allow the tunnel and ramp structures to meet the seismic performance requirements for a lifeline structure.

Ground densification for the ITT is required to elevation -30 m (Geodetic) onshore and to elevation -35 m in-river. For the Concept Design, it is assumed that the ground improvement is needed under the full length of the immersed tunnel and cut & cover tunnel including the ramps and open cut sections. The ground improvement is under the immersed tunnel structure (width of 47.1m) and under the backfill (width of approximately 20m each side of the ITT), giving a total width of approximately 90m for the ground improvement. This represents approximately 1 million cubic meters of soil improvement.

5 Tunnel Construction

5.1 Tunnel Element Immersion

CST assumed that the ITT tunnel elements are constructed off site, in a dry dock facility, and floated into place when needed (see drawing IT909 in Appendix A). At this time, a suitable dry dock facility has not been identified. Other construction options can be considered, but have not been developed by CST.

In the river, the construction sequence of the ITT begins with ground improvement, and is followed by dredging (CST assumed that the ground improvement would be done only below the level of the dredging, so that the dredging is not removing previously installed ground improvements unnecessarily). A levelling layer of gravel, approximately 1m thick, is installed on top of the ground improvement. Each tunnel element is then sequentially immersed using ballast tanks and onto temporary supports under each corner of the element; two on the previously installed neighbouring tunnel elements and two at the free end of the newly installed tunnel element, where each of the two supports has adjustable jacks to allow the final geometry of the element to be achieved. Once set to the correct geometry, the space between the underside of the tunnel elements and the gravel bed (approximately 0.5m thick) is then filled with grout. CST assumed that this will be done with the use of inflatable grout bags due to environmental constraints in the river.

5.2 Tunnel Locking fill, Backfill and Protection

After immersion of the tunnel elements is completed, the tunnel locking fill is placed in stages on both sides of the tunnel, up to 5m above the tunnel soffit level. The locking fill is placed as quickly as possible to fix the tunnel element horizontally after element immersion. The tunnel is fixed vertically by overweight from water in the ballast tanks, friction from the foundation pressure adds to the capacity against horizontal forces and movements.

In general, backfill is placed on top of the locking fill and consists of similar material as the locking fill. To protect the tunnel from accidental loads from ship traffic, such as dragged anchor, dropped anchor and sunken ship impact, CST assumed that there will be a 2.0m thick layer of rock armour placed on top of the tunnel. For scour protection purposes, CST assumed that this layer needs to be tied into the existing tunnel armouring as shown on drawing IT903 in Appendix A.

The size of the rock armour depends on the maximum speed of river for an extreme event, which is still to be defined. The thickness of the protection depends on risk from ship traffic and size of the blocks for the rock armour (minimum two layers of armour rock). CST has not determined the size of the armouring at this stage and assumed the same size as was used for the existing tunnel, which appears to be reasonable.

Filter layers are included between the tunnel protection and backfill to prevent local scouring of the sand under the tunnel protection.

5.3 Temporary Excavations

5.3.1 In-River Sections

For the in-river sections, the new tunnel is placed in a trench next to the existing immersed tunnel. The trench is created by an open cut excavation with a 1V:2.3H (vertical to horizontal) slope on the side towards the existing tunnel and by a 1V:3H sloped excavation on the opposite side. These slopes are flatter than the minimum calculated by CST to allow for some conservatism at the concept design stage.

5.3.2 On-Shore Sections

To minimize the extent of dewatering excavations, the immersed tunnel section of the crossing is made as long as possible. The interface between the immersed tunnel and cut-and-cover tunnel sections of the tunnel is located where the top of the immersed tunnel structure is 1.0m below elevation 0.0 m (Geodetic).

For the excavation of the on-shore ITT construction, cut-and-cover ITT construction and sheet-pile supported ramp construction, critical sections have been analysed to confirm feasibility.

For the on-shore ITT construction, water table inside the excavation and behind the shoring system is balanced and a tie-back system connected to a continuous sheet-pile anchor wall is a reasonable approach for the required excavation.

For the proposed in-the-dry cut-and-cover construction, the analysed excavation depth is down to elevation -13.0 m (Geodetic). A combination of a tie-back system connected to a continuous sheet-pile anchor wall and a two-level strut system is a reasonable approach for this work. The interior of the sheet pile anchor walls is plugged with a concrete foundation, and pumps are used to de-water the excavation.

For the proposed in-the-dry approach ramp construction, the four analysed excavation depths, along with their individual shoring system, are summarized as follows.

- > Excavation Depth to elevation -11.5 m: A combination of a tie-back system connected to a continuous sheet-pile anchor wall and a two-level strut system.
- > Excavation Depth to elevation -10.5 m: A combination of a tie-back system connected to a continuous sheet-pile anchor wall and a two-level strut system.
- > Excavation Depth to elevation -6.5 m: A tie-back system connected to a continuous sheet-pile anchor.
- > Excavation Depth to elevation -4.0 m: A cantilever sheet-pile system.

For all sheet-pile supported, in-the-dry constructions, the shoring sheet-piles are assumed to extend into the lower permeability silty layer, for the purpose of estimating quantities. The top of the shoring sheet-pile is assumed to be at elevation +3.38 m (Geodetic), which is the assumed design flood elevation (design crest level) during construction.

For the approach ramp construction with excavation shallower than elevation -3.0 m, it is assumed that open cut excavation method will be adopted, in combination with a dewatering system and a concrete lining at the bottom of the excavation and along the side slopes to allow the ramps to be constructed in-the-dry.

6 Deas Slough Bridge and River Road Overpass

With the alignment of the new ITT options comes the need for a new crossing of Deas Slough. Appendix C shows a concept design for the bridge.

There is limited head room available for the new bridge crossing, and therefore CST assumed that the clearance unde the existing Deas Slough bridge is sufficient.

As part of the project, the Ministry asked CST to develop an option to continue River Road across Highway 99. Appendix C shows a concept for a new crossing over Highway 99.

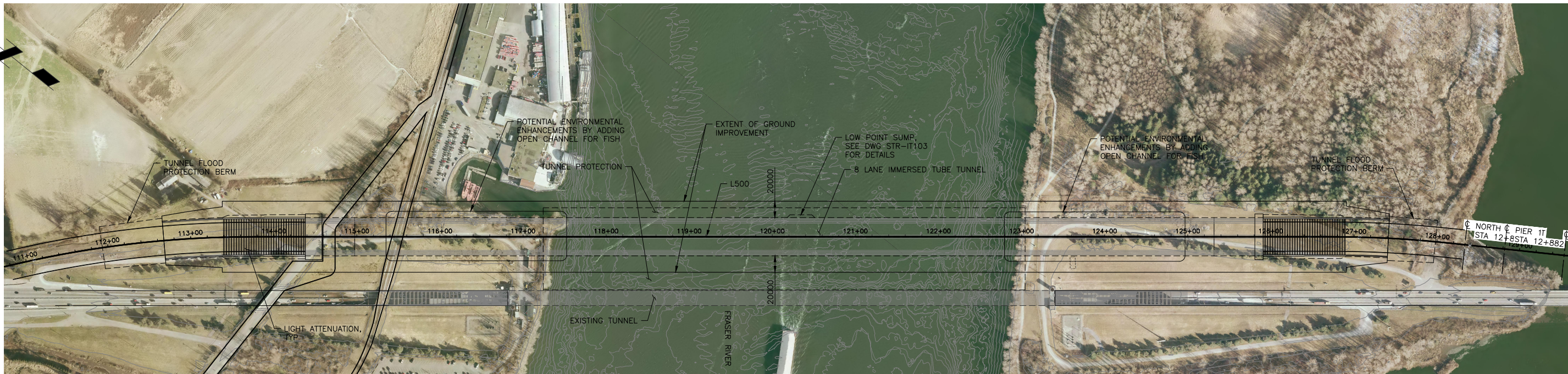
7 References

Navigational requirements:

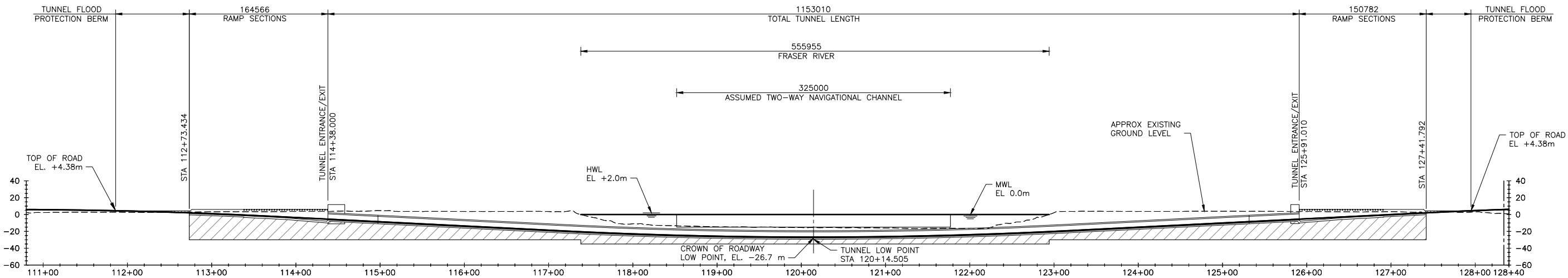
- > BCMoTI. Pattulo Bridge Replacement Project – Navigation Clearance Drawing. Drawing No. NAV-0001. Dated Nov 2018.
- > BC Transportation Investment Corporation. George Massey Tunnel Replacement Project. New Concession Bridge. Navigation Clearance Drawing. Drawing No. NAV-0001. Dated Sept 2016.
- > Geologic and seismic conditions:
 - > Stantec. Geotechnical Engineering Technical Summary Memorandum for the Proposed George Massey Crossing, Richmond/Delta, BC. Memo No.: GMC-GEO-002_B. Dated Oct 2019.
- > River hydraulic conditions:
 - > Northwest Hydraulic Consultants Ltd. George Massey Crossing: Preliminary CFD Modelling Results. Draft Report (NHC ref No. 3004977) . Dated Oct 2019.
- > Traffic volumes and composition:
 - > Stantec. George Massey Crossing Technical Services. Traffic and Geometrics Technical Memorandum. Draft. Dated Oct 2019.

Appendix A ITT Concept Drawings

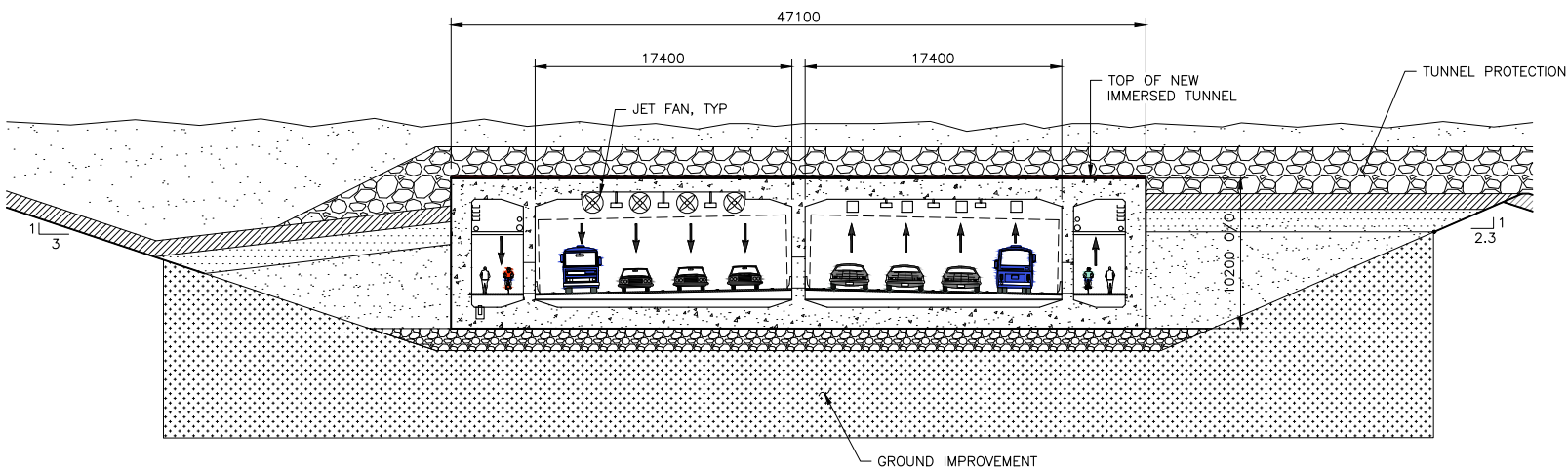
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PLAN
SCALE 1:2500



ELEVATION
SCALE 1:2500



TYPICAL CROSS SECTION
SCALE 1:250

ABBREVIATIONS

- B/O BOTTOM OF
C&C CUT AND COVER
EL ELEVATION
FLS FIRE AND LIFE SAFETY
HWL HIGH WATER LEVEL
ITT IMMERSED TUBE TUNNEL
LAS LIGHT ATTENUATION STRUCTURE
LWL LOW WATER LEVEL
M&E MECHANICAL & ELECTRICAL
MEP MECHANICAL, ELECTRICAL AND PLUMBING
MUP MULTI-USE PATH
MWL MEAN WATER LEVEL
STA STATION
TYP TYPICAL

GENERAL NOTES

- DIMENSIONS ARE IN MILLIMETRES UNLESS OTHERWISE NOTED.
- ELEVATIONS ARE IN METRES (GEODETIC DATUM).
- THE EXISTING TUNNEL LOCATION AND THE GROUND LEVELS ARE SHOWN AS 'APPROX' SINCE ACCURATE SURVEY DATA IS NOT AVAILABLE.
- DRAWINGS ARE BASED ON CONCEPT DESIGN, AND ARE ISSUED FOR GENERAL PLANNING AND COSTING PURPOSE.
- TUNNEL FIRE & LIFE SAFETY DESIGN ASSUMES TUNNEL OPERATION AND TRAFFIC MANAGEMENT SYSTEMS IN ACCORDANCE WITH REQUIREMENTS OF NFPA502. CONSULTATION WITH STAKE HOLDERS AND AUTHORITIES WILL BE REQUIRED DURING PRELIMINARY DESIGN.

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Ministry of Transportation & Infrastructure
South Coast Region

LOWER MAINLAND HIGHWAY DISTRICT
HIGHWAY 99
MASSEY CROSSING – IMMERSED TUNNEL
GENERAL ARRANGEMENT

PREPARED UNDER THE DIRECTION OF

ENGINEER OF RECORD

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DESIGNED

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SCALE

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PROJECT No.

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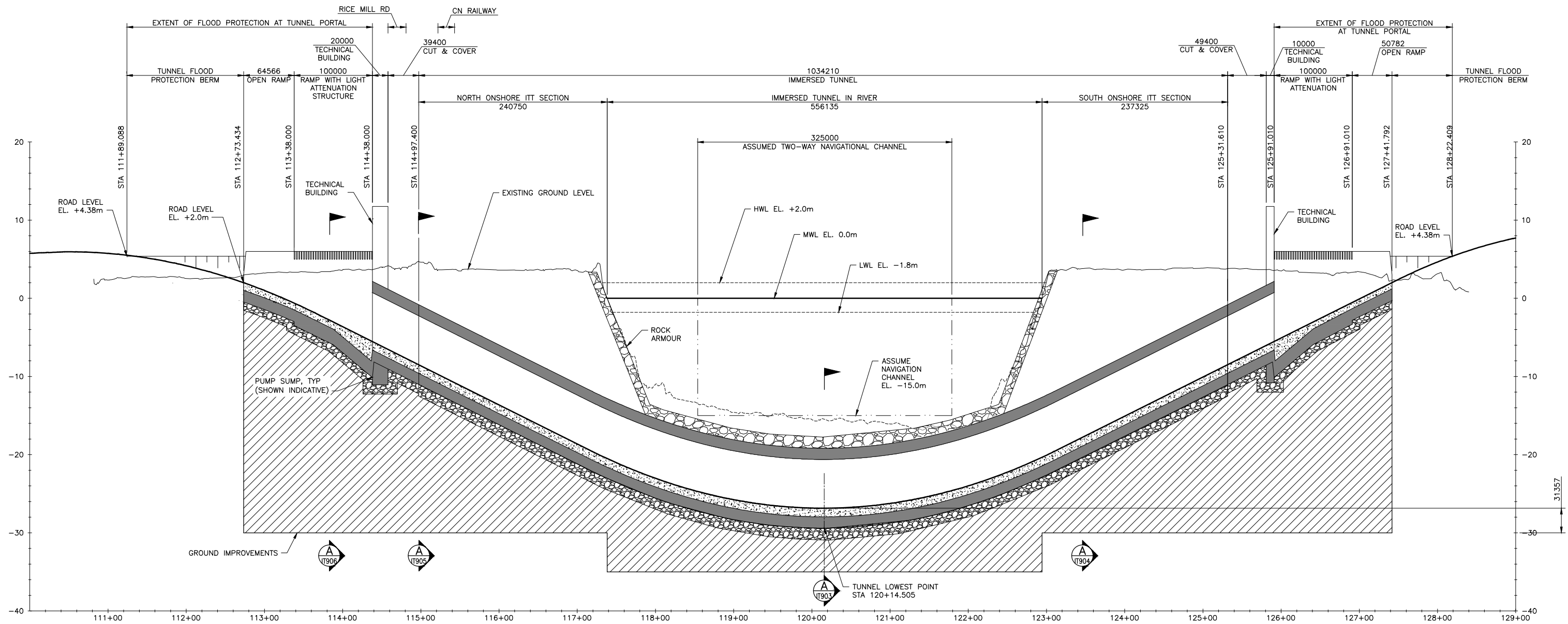
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IT901

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TUNNEL LONGITUDINAL PROFILE
HORIZONTAL SCALE: 1:2500
VERTICAL SCALE: 1:250

NOTES:

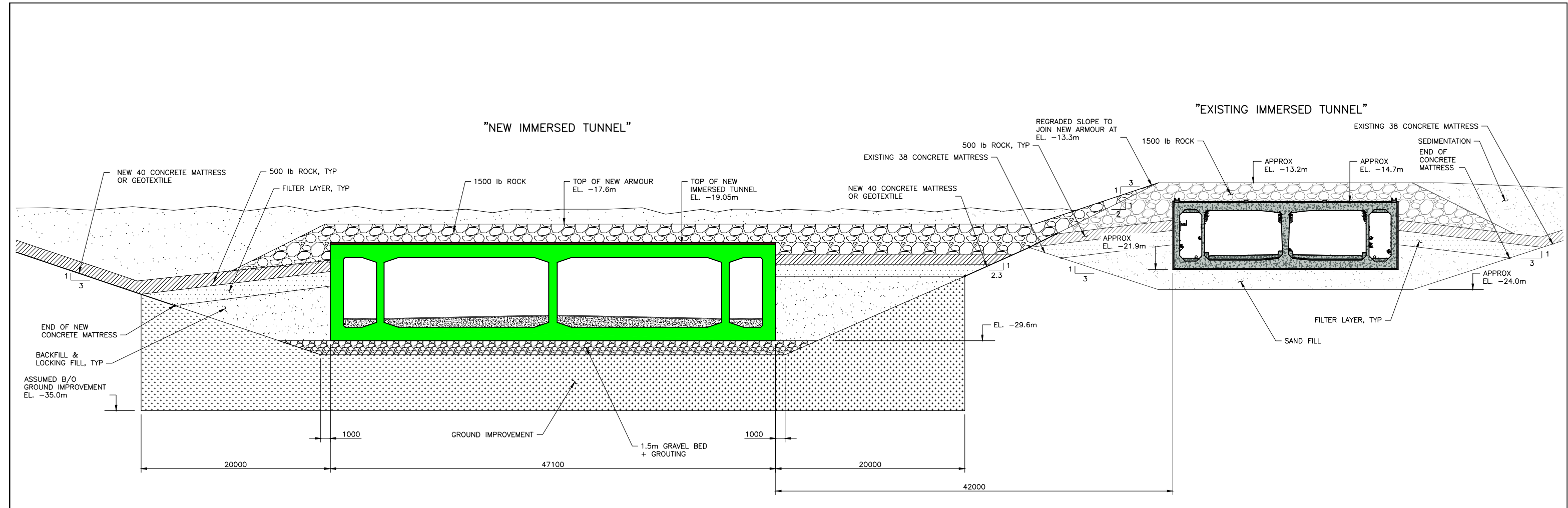
- SEE GENERAL NOTES AND ABBREVIATIONS DWG IT901.

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SECTION **A** IMMersed TUNNEL IN RIVER
SCALE 1:200 **IT902** STA 120+14.505

NOTES:
1. SEE GENERAL NOTES AND ABBREVIATIONS DWG GEN-IT901.


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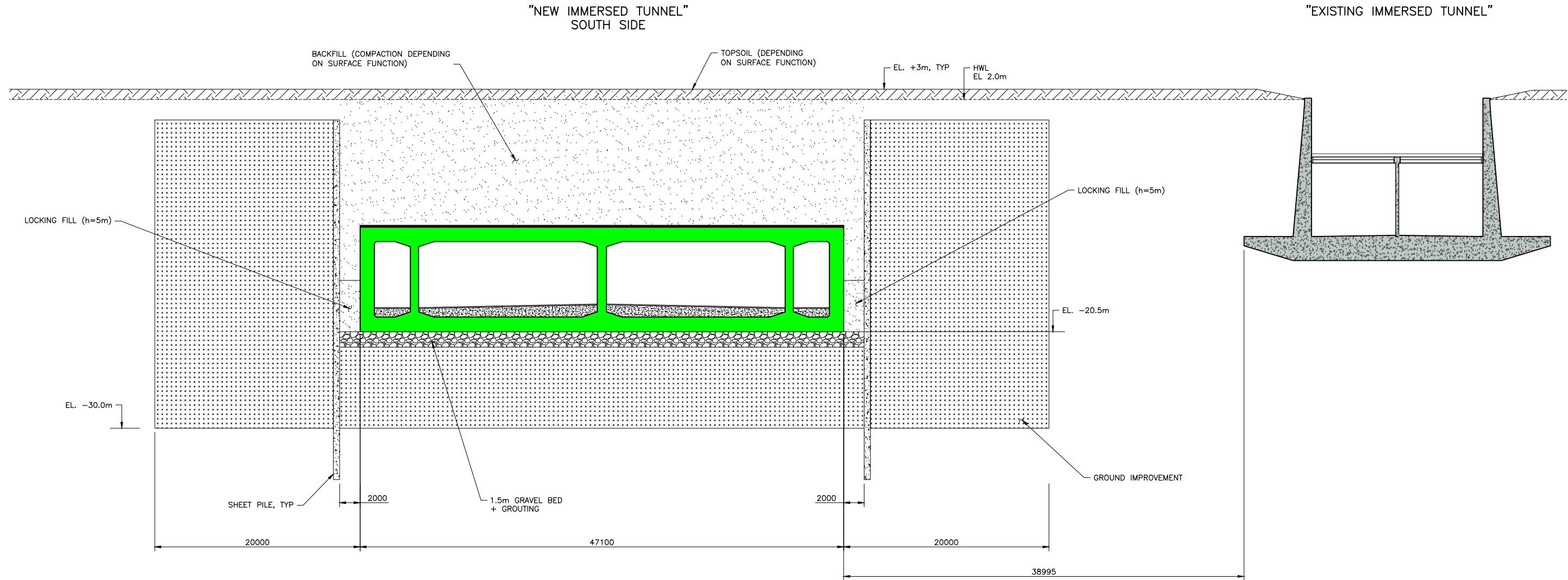
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Ministry of Transportation & Infrastructure
South Coast Region

LOWER MAINLAND HIGHWAY DISTRICT
HIGHWAY 99
MASSEY CROSSING – IMMersed TUNNEL
RIVER SECTION

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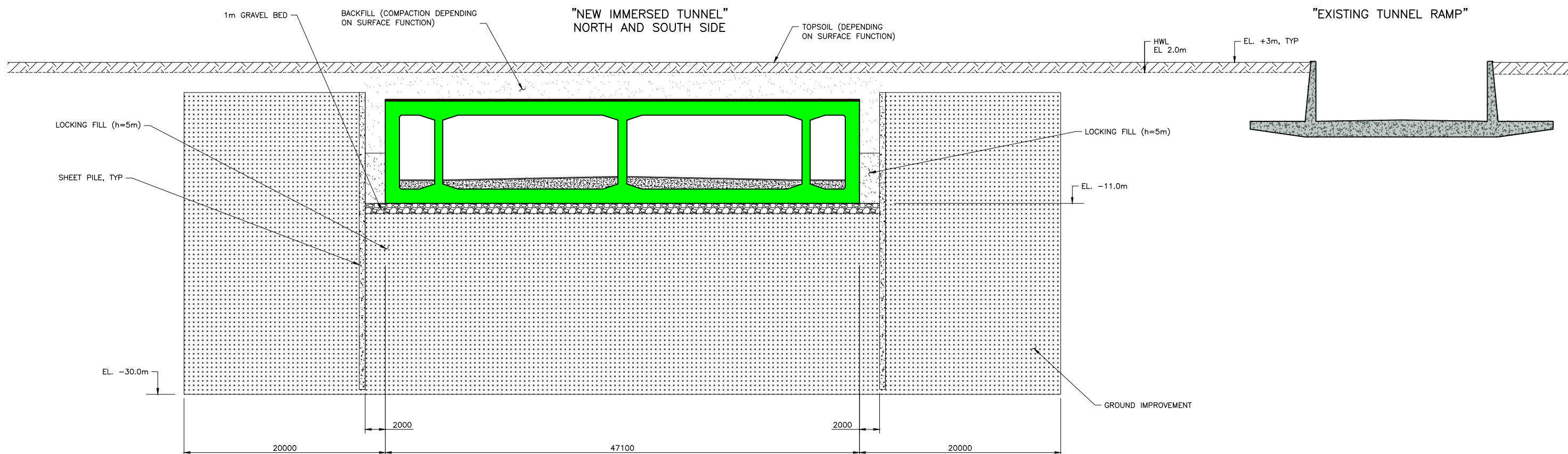


SECTION (A) IMMERSSED TUNNEL ON-SHORE
SCALE 1:200 IT902 STA 123+42.288

NOTES:
1. SEE GENERAL NOTES AND ABBREVIATIONS DWG IT901.

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SECTION (A) IMMERSED TUNNEL CUT & COVER SECTION
SCALE 1:200 (T902)
NORTH SHORE SHOWN, SOUTH SHORE SIM
STA 115+16.849

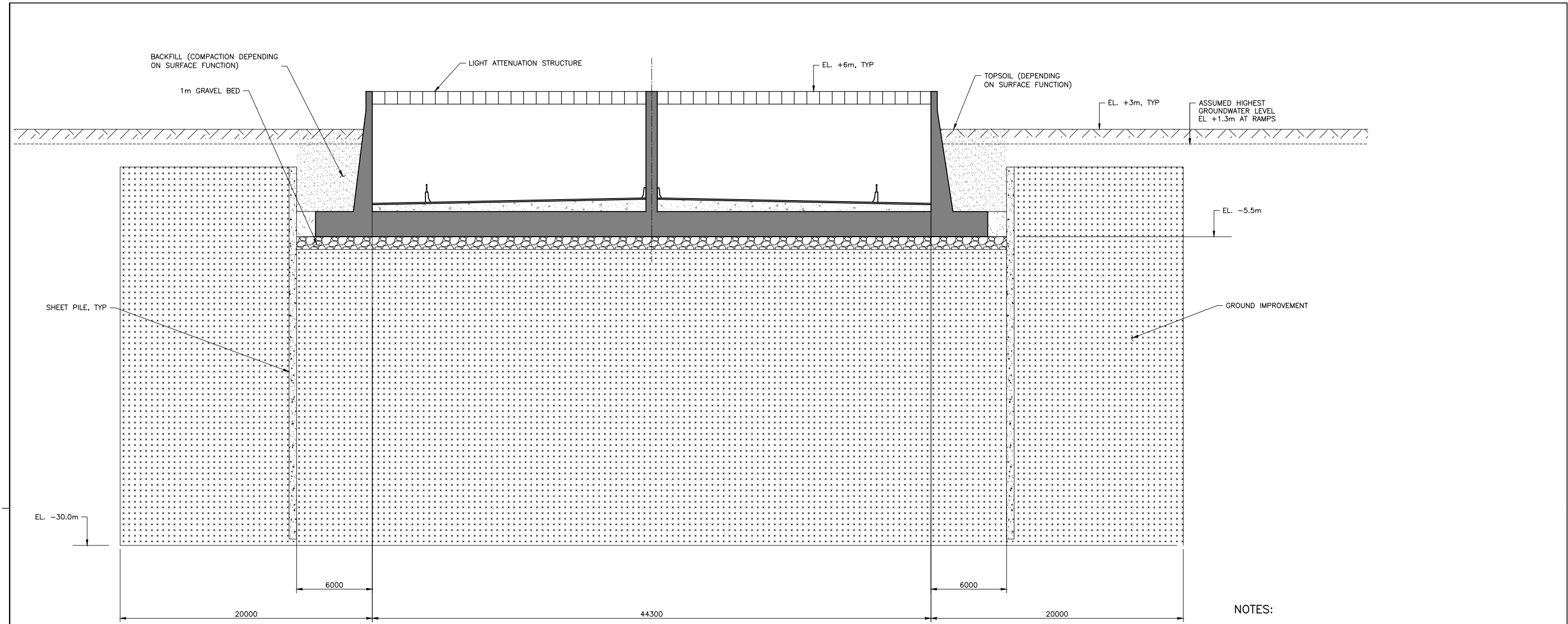
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- SEE GENERAL NOTES AND ABBREVIATIONS DWG IT901.

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SECTION **A** IMMERSSED TUNNEL RAMP WITH LIGHT ATTENUATION STRUCTURE
SCALE 1:150 IT902
NORTH SHORE SHOWN, SOUTH SHORE SIM
STA 113+78.956

NOTES:
1. SEE GENERAL NOTES AND ABBREVIATIONS DWG IT901.


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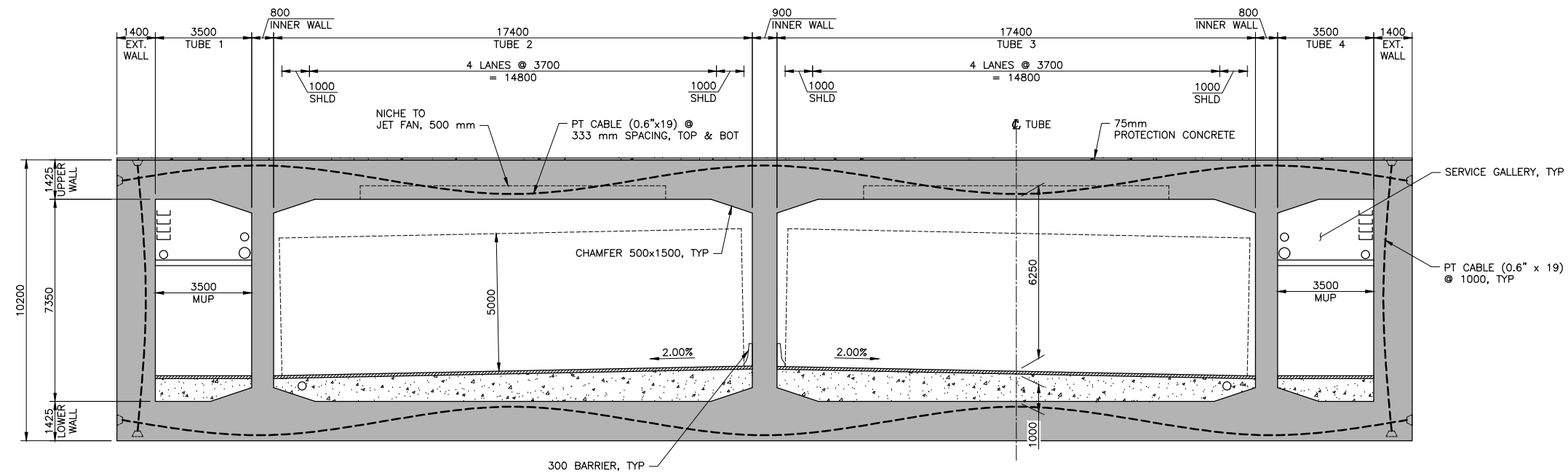
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South Coast Region

LOWER MAINLAND HIGHWAY DISTRICT
HIGHWAY 99

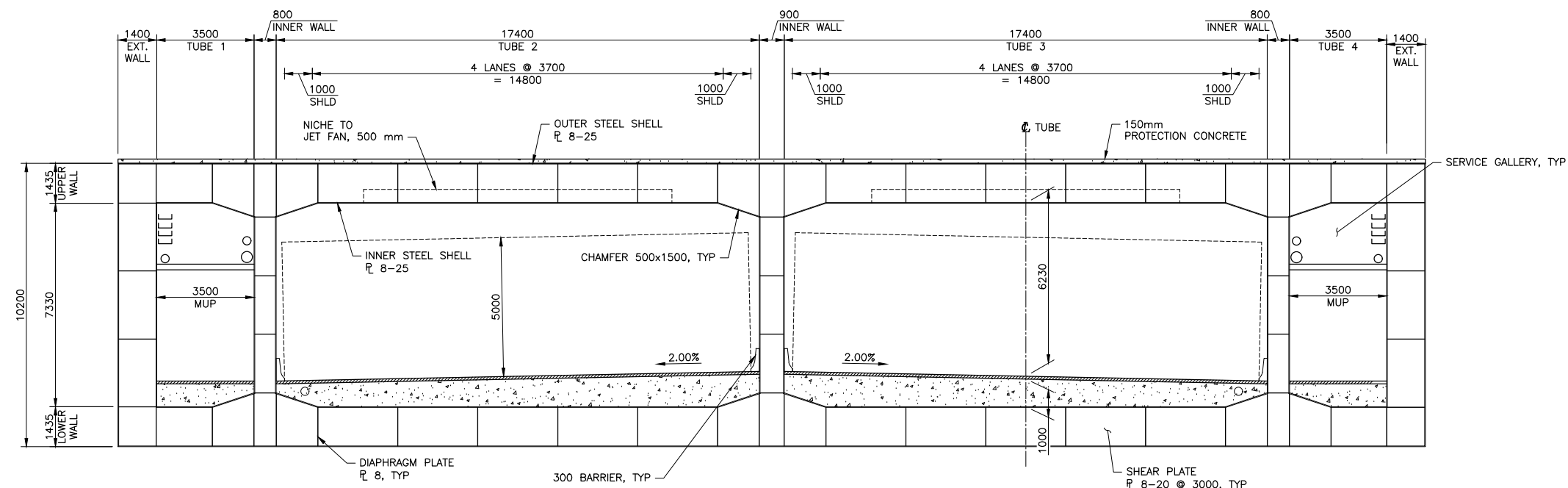
MASSEY CROSSING – IMMERSSED TUNNEL
NORTH & SOUTH RAMP WITH LAS SECTION

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SECTION AT TYPICAL ROADWAY

SCALE 1:100
ALTERNATIVE 1: POST-TENSIONED CONCRETE



SECTION AT TYPICAL ROADWAY




SCALE 1:100
ALTERNATIVE 2: STEEL-CONCRETE-STEEL COMPOSITE

NOTES:

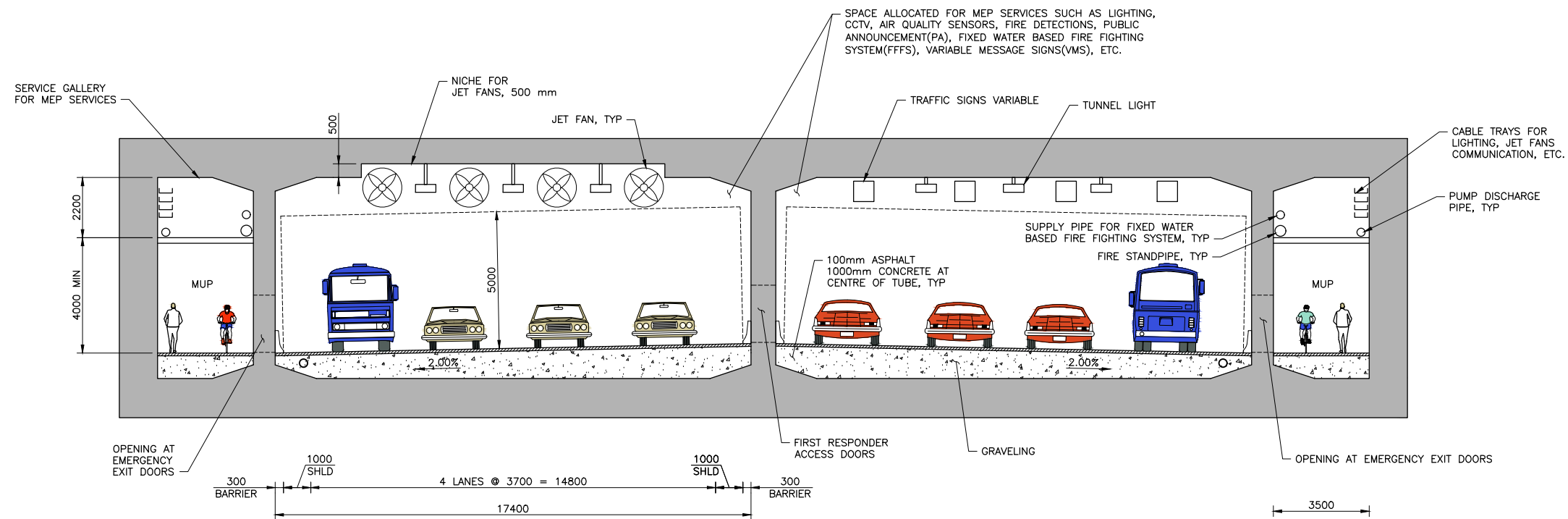
1. SEE GENERAL NOTES AND ABBREVIATIONS DRAWING IT901.

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LOWER MAINLAND HIGHWAY DISTRICT HIGHWAY 99 MASSEY CROSSING — IMMERSED TUNNEL TUNNEL ELEMENT STRUCTURAL DIMENSIONS			
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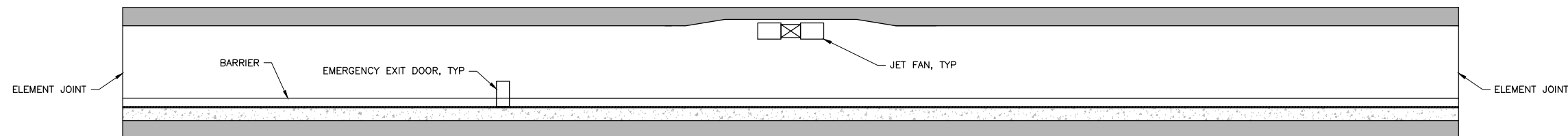
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TYPICAL SECTION

TYPICAL SECTION WITH MEP AND TUNNEL OPERATION INSTALLATIONS

SCALE 1:100

(DIMENSIONS SIMILAR TO TYPICAL ROADWAY SECTION U/N)



TYPICAL LONGITUDINAL SECTION

SCALE 1:200

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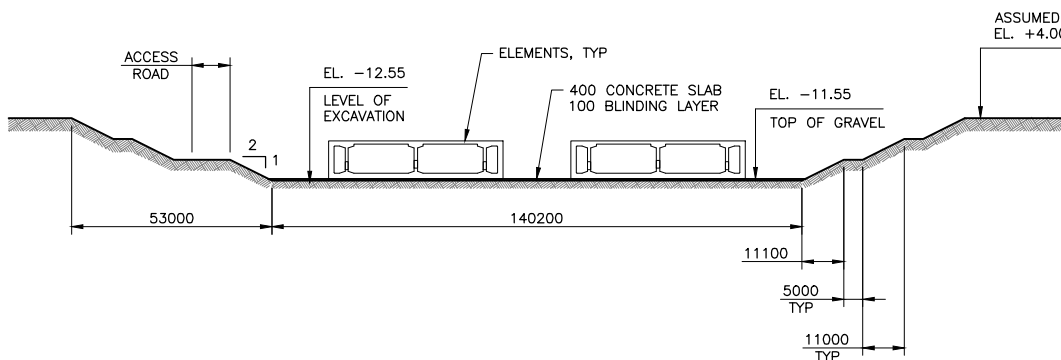
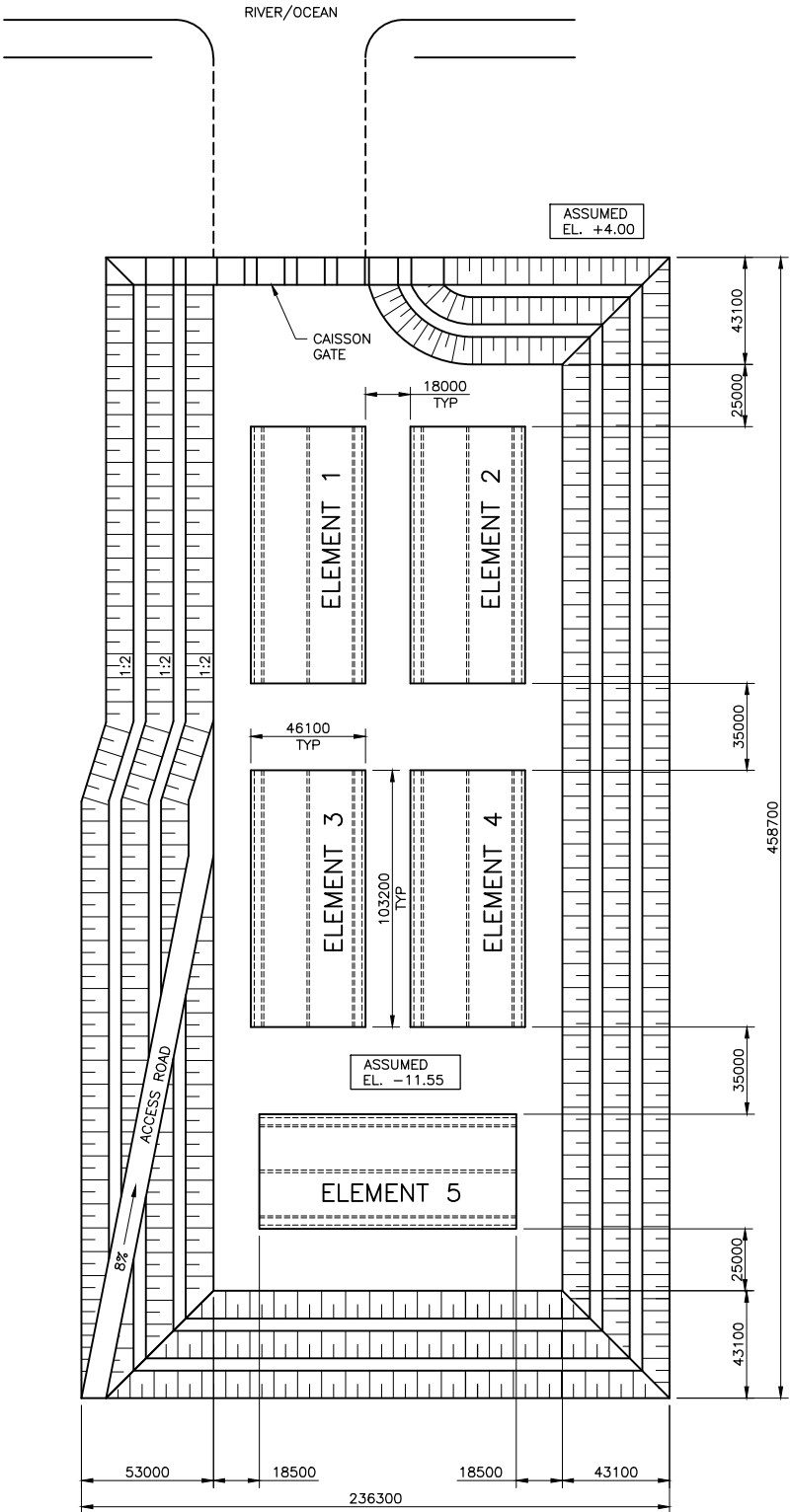
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LOWER MAINLAND HIGHWAY DISTRICT HIGHWAY 99 MASSEY CROSSING – IMMERSED TUNNEL TYPICAL ELEMENT SPACE PROOFING			
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- NOTES:**
1. SEE GENERAL NOTES AND ABBREVIATIONS DRAWING IT901.
 2. THE DRY DOCK DESIGN IS SUBJECT TO ACTUAL CONDITIONS AT THE CONSIDERED LOCATION INCLUDING LEVELS AND GROUND CONDITIONS.
 3. SLOPES OF DRY DOCK ARE ASSUMED AT 1:2 (WITH PLATEAU EFFECTIVELY 1:2.6), THE DESIGN IS SUBJECT TO ACTUAL GROUND CONDITIONS.

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Ministry of Transportation & Infrastructure South Coast Region			
LOWER MAINLAND HIGHWAY DISTRICT HIGHWAY 99			
MASSEY CROSSING — IMMERSED TUNNEL POSSIBLE DRYDOCK PLAN			
PREPARED UNDER THE DIRECTION OF		DESIGNED — DATE 2019-11-15	
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Appendix B Concept Design Details

B.1 Tunnel Space Requirements

This section presents conceptual considerations relating to the space requirements (often referred to as tunnel space proofing) of the tunnel with respect to design standards, code requirements, and operational safety, performance, reliability, availability, maintenance and user comfort with particular reference to Fire Protection and Life Safety (FLS) and Mechanical and Electrical equipment and associated systems (M&E). There are no differences in considerations for 6 or 8 lane options.

B.1.1 Fire – Life Safety Considerations

The concept design of the space proofing of the road tubes in the ITT has been based on NFPA 502 for a Category D tunnel. The tunnel category defines the safety installations in the tunnels, and Category D has the highest requirements for safety installations due to the traffic volume.

The design for the tunnel will mitigate hazards in case of an emergency incident by the following means, representing a good-practice, code compliant tunnel:

- > *Emergency exit doors* will be located at distances not to exceed 300m along the tunnel to allow tunnel users to reach a place of safety. Required distance between doors will be defined by egress analysis. However, CST's consideration, subject to egress analysis, is to provide a maximum spacing of one door per tunnel element (roughly every 105m).
- > To prevent MUP users from accidentally entering the road tubes via the emergency exit doors, it shall only be possible to open the doors from the road side. Access from the MUP's for emergency responders will need to be considered in the final design.
- > The emergency exit from the roadway will be the exit doors to the adjacent parallel MUP. In the event of an emergency somewhere in the tunnel that stops traffic, the vehicles that are already past the accident site can simply drive out of the tunnel. Those trapped inside the tunnel by the accident, or those who otherwise are unable to drive out, leave their vehicle and use the emergency exits to vacate the tube via the pressurized MUP. Emergency exits will assist vehicle occupants, particularly those located behind the fire location, to leave the tunnel without their vehicles and reach a safe place via the MUP acting as an exit passageway.
- > *Egress Pathway.* The tunnel roadway surface will also be used as escape route during a fire, hence the roadway will be part of the egress pathway (as defined by the applicable codes).
- > *Wayfinding* will be provided to aid evacuation of the tunnel and can include items such as specific markings along pathways, pathway lighting, and additional illumination.

- > *Fire Alarm and Detection:* Two independent systems of identifying and locating a fire will be provided. Fire alarm detection within 15m of the fire detection system is foreseen.
- > *Automatic fire detection systems (AFDS)* should be able to detect a tunnel fire incident within 90 seconds or better. AFDS will be zoned to correspond with the tunnel ventilation and FFFS.
- > An approved *Fire Alarm Control Panel (FACP)* will be provided in accordance with NFPA 72 Chapter 10 and 14. The FACP will be used to receive signals and to initiate alarms. If an approved SCADA system is provided, the SCADA system will be utilized to initiate alarms in response to a fire emergency. Provisions will be included to stop all traffic operation.
- > *Emergency lighting* will be provided to guide tunnel users to evacuate the tunnel on foot; In the event of failure of the normal power supply an alternative source of power will maintain power to operational and safety systems and permit use of the tunnel to continue;
- > *Illuminated directional signs* indicating the distance to the nearest emergency exits on the side walls will be provided at distances of no more than 25 m as per NFPA 502 §7.16.1.2 recommendations;
- > *Standpipe System:* Class I system will be provided with hose connections located in tunnels at 85 m maximum intervals in compliance with NFPA 502 §10.4.2;
- > Hose connections will have 65 mm external threads in accordance with NFPA 1963 and equipped with caps to protect hose threads in compliance with NFPA 502 §10.4.4;
- > *Fire Hydrants* on open ramps: Water supply will be provided with fire hydrants located at 305 m minimum intervals for use by the emergency services in compliance with NFPA 502 §7.8;
- > Tank for water supply of FFFS, standpipe system and fire hydrants will be established at one portal; water supply will be capable of supplying the system demand for a minimum of 1 hour in compliance with NFPA 502 §9.3 and §10.2.1; Make up water to water tank from the municipality water network.
- > *Fire pumps:* Fire pumps will be installed, inspected, and maintained in accordance with NFPA 20;
- > *Portable fire extinguishers* with a rating of 2-A:20-B:C, will be located in approved wall cabinets at intervals of not more than 90 m; they will be selected, installed, inspected, and maintained in accordance with NFPA 10. Consideration should be given to incorporating into the alarm system a means for detecting the removal of an extinguisher;

- > *Hydrocarbon detection:* Pump sumps, drainage water and pump stations will be monitored for hydrocarbons. Detection of hydrocarbons in the tunnel drainage effluent will initiate both a local and a remote alarm as per NFPA 502 §7.12;
- > Access for emergency services will be provided to allow emergency vehicular services to gain access through both portals;
- > *Intervention by emergency services* will be via cross-doors between the two road tubes; Number of doors to be agreed with the Emergency Services.
- > *For structural integrity,* the tunnel will be designed in accordance with the fire curve defined by PIARC (World Road Association) in their Road Tunnels Manual;
- > *Traffic Controls:* CCTV together with a comprehensive system of signs and signals will be developed in close cooperation with the Overseeing Organisation (which has the overall responsibility for authorising such installations on its motorways and other trunk roads) in compliance with NFPA 502 §7.6. Appropriate levels of equipment for measurement of traffic speed and density should be provided;
- > Direct approaches to the tunnel will be closed following activation of a fire alarm within the tunnel. Approaches shall be closed in such a manner that responding emergency vehicles are not impeded in transit to the fire site;
- > Traffic within the tunnel approaching (ahead of) the fire site will be stopped prior to the fire site until it is safe to proceed as determined by the incident commander;
- > *Emergency management system:* Systems relating to emergency points and the response to tunnel emergencies shall be linked with the tunnel plant monitoring and control centre in compliance with NFPA 502;
- > Traffic composition and numbers will influence tunnel ventilation, power supply and distance to emergency exit doors;
- > The proposed electrical system shall support life safety operations, fire emergency operations, and normal operations;
- > Emergency electrical circuits shall remain functional for a period of not less than 1 hour for the anticipated fire condition;
- > The following systems shall be connected to the emergency power system:
 - > Emergency lighting
 - > Tunnel closure and traffic control
 - > Exit signs

- > Emergency communication
- > Tunnel drainage
- > Emergency ventilation
- > Fire alarm and detection
- > Closed-circuit television or video
- > Firefighting systems

Fire emergency systems such as FFFS and fire standpipe and emergency ventilation are not considered in the MUP as the fire load in these tubes will be very limited. However, lighting, emergency lighting, CCTV and public announcement systems should be installed for safety, security and comfort of users.

Outside the tunnel portals, space for operation and safety features shall be allocated, such as space for closure barriers, cross overs for closures during maintenance, rendez-vous points for fire brigade before/during fires and service roads for stopped abnormal load vehicles etc.

B.1.2 Mechanical & Electrical (M&E) Requirements

For the concept of the immersed tunnel elements the following are used as design requirements:

- > Dangerous goods will be allowed, which potentially can have a heat release rate of 200-300 Mega Watts according NFPA 502.
- > The length of the tunnel is approximately 1153m.
- > The tunnel will have 6-lanes (2 x 3) or 8-lanes (2 x 4) road lanes and two MUP tubes.
- > Contraflow traffic will under normal conditions not be allowed in the tunnel, except during planned maintenance.
- > Motorized traffic, except for small services motor vehicles for maintenance or cleaning of the MUP, will not be allowed inside the MUP.
- > Maximum size of a liquid tanker for the drainage system to cope with is 30m³ (retention volume in the tunnel).
- > The tunnel will be essential for transport over the Fraser river and therefore down time due to maintenance and repairs shall be kept to a minimum.
- > To mitigate the risk of long-term tunnel closures a Fixed Fire Fighting System (FFFS) is considered to prevent spread of fire between vehicles and limit the fire size.

B.1.3 M&E Space Requirements

Space provisions for tunnel M&E systems has been carried out at concept level to include the following systems:

Tunnel ventilation

- > Tunnel ventilation based on jet fans for day to day ventilation and smoke management in case of a fire.
- > Pressurization system for MUP
- > Ventilation system for MUP
- > Ventilation systems for pump sumps

Detection

- > Fire detection system for tunnel
- > Fire detection for technical rooms
- > Door detection
- > CO, NO_x / NO₂ and visibility
- > Air velocity

Firefighting Systems

- > Fire standpipe system for tunnel and open road ramps
- > Fixed water-based Fire Fighting System (FFFS) for tunnel
- > Fire gas extinguishing (for el-equipment)
- > Fire foam systems (for drainage sumps)

Drainage

- > Drainage system for tunnel low point
- > Ramp drainage

Cooling

- > Cooling of all power equipment (in tunnel and portal service buildings)
- > Cooling for HVAC in portal service building

Low Voltage (LV) power / Lightning Earthing

- > Power supply and distribution
- > Power backup as generators and UPS for tunnel and MUP

- > Earthing and equipotential bonding for tunnel and MUP

Lighting/Emergency Lighting

- > Tunnel lighting systems
- > Emergency lighting system

Information and Communication

- > Communications systems
- > ITS (intelligent traffic system)
- > SCADA and control and management systems
- > Data network
- > CCTV

B.1.4 Mechanical & Electrical (M&E) General

Ventilation

A longitudinal ventilation system based on jet fans is considered for the tunnel for the purpose in this concept stage of the project development. The system will be applied both for day to day ventilation and emergency ventilation in case of a fire.

A longitudinal ventilation system takes fresh air via the tunnel entrance portal, the jet fans transport the air through the tunnel diluting the emissions and expel the polluted air via the exit portal.

In case of a fire the tunnel will be smoke free from the entrance portal to the fire and smoke logged from the fire to the exit portal. This signifies that vehicle users trapped upstream of the fire will be able to evacuate the tunnel protected by the ventilation system, while vehicles downstream of (behind) the fire maybe engulfed in smoke, which is acceptable as they are expected to drive out of the tunnel (see Figure B.1).

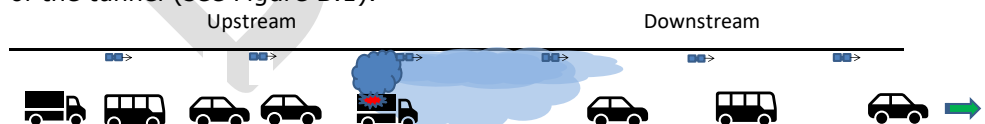


Figure B.1: Illustration of traffic protected of by ventilation system

An intelligent traffic management system shall be installed which in case of standstill within ~1.5km outside the exit portals of the tunnel tubes, stops more vehicles from entering the tunnel until the standstill is resolved.

As part of the FLS strategy, to pressurize the MUPs airtight gates shall be provide at each end of the MUPs. The gates will close in case of a fire alarm and will be provided with a self-closing door, enabling MUP users and evacuees to exit the MUP.

Because of its relatively short length, the tunnel will be naturally ventilated due to the piston effect of the traffic (normally for day to day ventilation), and the jet fans will only be activated at very low traffic speeds or with congestion.

Drainage

A low point pump sump including pumps is required at the deep point of the tunnel to remove incoming liquids as water from cleaning or leakage of e.g. petrol from a tanker. The capacity of the sump shall minimum be 30m³ equal to the capacity of a tanker truck.

Portals will be provided with ramp pump sumps to prevent rainwater entering the tunnel. The capacity of the installation will be based on an extreme rainfall event with a proposed return period of 100 years, taking into account the effects of climate change.

Discharge of water will be via oil separators or equivalent.

Technical Building

A portal technical building shall be provided at each portal – a primary building at one side and a secondary at the other. The technical buildings can in principle be below ground. The primary building shall besides a main control room contain rooms for M&E systems not installed in the tunnel e.g. water tank and pumps for standpipe system, water tank and pumps for Fixed water based Fire Fighting System, fans for pressurization system, communication, LV, HV, power backup etc. The secondary building is mainly for the second supply for the pressurization system, but other systems can also be placed here.

Continuous power is required for safe tunnel operations, even in emergencies. As such, emergency back-up generators are required.

The MUP's will require drainage, ventilation, lighting, emergency lighting, CCTV and PA.

B.1.5 Summary of Space Requirement for FLS and M&E

Road tunnels

Allowance for M&E space of 1.1m above the envelope of the traffic will be reserved for road services such as lighting, CCTV, air quality sensors, fire detection, public announcement, fixed firefighting systems, VMS and jet fans as per Figure B.2.

Recesses with a height of 0.5m, to accommodate the upper parts of the jet fans will be provided in the tunnel ceiling above the M&E space, as shown in Figure B.2 below. One niche is foreseen for each element.

Additionally, a 200mm allowance has been considered between the top corners of the traffic envelope and the tunnel lining to allow services to rise up along the tunnel walls.

Consideration has further been given to the operational requirements listed below. For this concept design, these requirements are not assumed to impact the general space proofing.

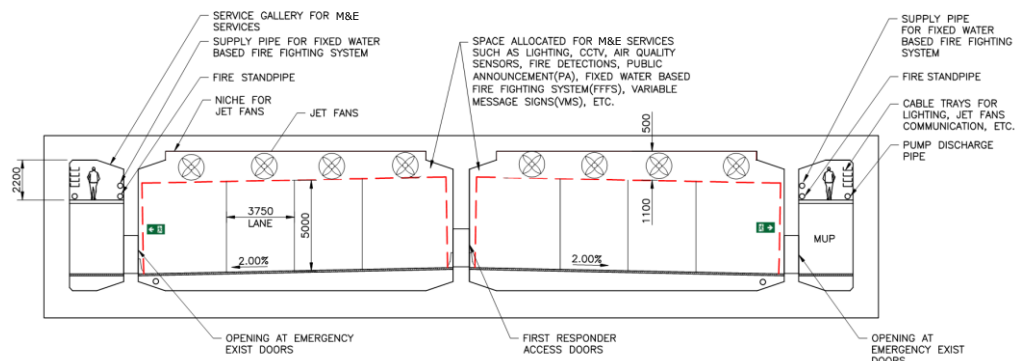


Figure B.2: M&E Space requirements - ITT Cross-Section Profile

Technical gallery for services

A dedicated technical gallery, with a clear height of 2.2m, for M&E installations above each MUP, such as fire mains, pipes and electrical and communication cables will be provided above each MUP as shown in Figure B.3.

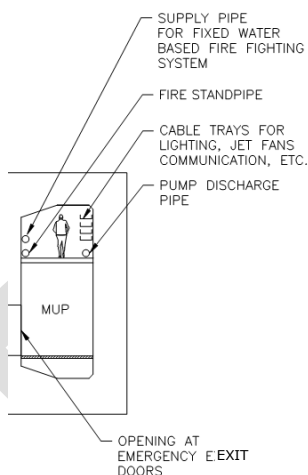


Figure B.3: Technical Gallery

Tunnel low point element

The low point tunnel element differs from the other elements by having a sump installed below the road surface in each tube. Further this element will locally be extended with a ~3 m bead adjacent to one of the MUPs to provide a pump sump for the tunnel low point as illustrated in Figure B.4.

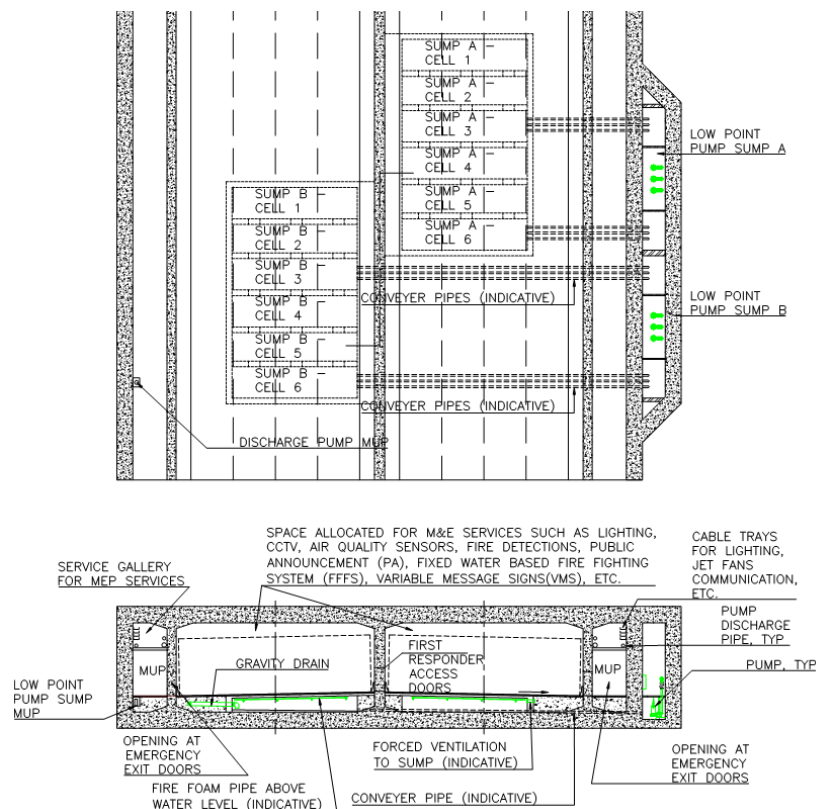


Figure B.4: ITT Low point element, with low point sumps and pump sumps. Plan and section view.

B.2 Assumptions for Structural Design

In the permanent situation, a safety against uplift (permanent loads divided by uplift) greater or equal to 1.06 has been aimed for (without the weight of tunnel protection). This allows the tunnel to remain submerged, while not increasing the stress on the underlying soil which could cause excessive settlements.

The permanent loads comprise structural concrete, ballast concrete and backfill above tunnel structures (corners and toes) up to the tunnel roof.

The most unfavourable combination of low permanent loads and high uplift load has been considered.

In the temporary floating situation, a freeboard greater than 0.2m has been aimed for. Ballast concrete has not been considered in this situation. In addition, a "trimming" load corresponding to water added in ballast tanks to trim the element to horizontal in the transverse direction has been considered. The most unfavourable combination of heavy structural concrete and light water has been considered.

It is assumed that accidental loads for ship traffic, such as "dropped anchor", "dragged anchor", "horizontal ship impact" and "sunken ship" are either eliminated or will not be governing for the immersed tunnel structural design, hence not add additional cost to the structure. Based on experience, the layout of the existing immersed tunnel and a future navigation channel that is deeper

than the existing navigation channel, it is believed that this assumption is reasonable.

B.3 Structural Design

B.3.1 ITT Tunnel Types

Early in the project, it was determined that the three traffic lanes plus shoulders of the 6 lane option could be accommodated in one tube of the ITT using a standard reinforced concrete structural system. However, in order to accommodate four traffic lanes plus shoulders of the 8 lane option in one tube, either a post-tensioned concrete cross section or a steel-concrete-steel sandwich plate section is required to maintain water tightness.

These latter two structural systems are not very common in ITT construction, but they are used, and are both feasible. Therefore, CST investigated the following for the 8 lane ITT:

- Type 1 - Concrete section with post tensioning in top and bottom slabs and the outer walls; and
- Type 2 - Steel – Concrete - Steel, sandwich type (SCS-type) for the entire cross section.

The Type 1 post-tensioning system has been used in various ITTs in the world; the latest example is the Björvika ITT in Oslo, Norway. The southernmost element has a widening cross section due to its proximity to an intersection, the top and bottom slabs are post tensioned.

Also, the Louis-Hippolyte Lafontaine Bridge–Tunnel in Quebec (Canada) used this type of construction, and is one of the largest prestressed concrete structures in the world and is the longest bridge-tunnel in Canada. The tunnel opened in 1967.

The Type 2 SCS system is more common, with examples including: Shinwakato (2007), Osaka Port (2004), Naha Airport (2003) in Japan, and Shenzhong link (under construction) in China.

B.3.2 Material Properties

For this concept design of the immersed tunnel elements, the following material properties (namely specific weights) and variations are assumed (based on several past ITT projects that our team has been involved in):

Type 1, Concrete with post tensioning

Structural concrete (unreinforced)	$\gamma_{sc} = 23.5\text{kN/m}^3 \text{ (+/-1.5\%)}$
Reinforcement content	$m_r = 130\text{kg/m}^3 \text{ to } 180\text{kg/m}^3$

Type 2, SCS type

Self-compacting concrete (unreinforced) $\gamma_{sc} = 22.7\text{kN/m}^3$ (+/-1.5%)

Structural Steel content $m_r = 190\text{kg/m}^3$ to 250kg/m^3

General properties:

Ballast concrete $\gamma_{sc} = 22.8\text{kN/m}^3$ (+/-1.5%)

Backfill $\gamma'_{bf} = 10\text{kN/m}^3$ (+/-1.5%)

Fresh water ($\gamma_{w,\min} = 9.781\text{kN/m}^3$) is assumed as the lower bound specific weight and a brackish water at, 20 ppt ($\gamma_{w,\max} = 9.967\text{kN/m}^3$) as the upper bound.

Water $\gamma_w = 9.873\text{kN/m}^3$ (+/-0.95%)

B.4 Calculation methodology

The top and bottom slabs of the 8 lane ITT option are in the order of 1.4m to 1.5m thick. The outer wall is of similar thickness to help balance the design.

Internal walls have been dimensioned to be in the order of 0.8m to 0.9m thick. Thinner walls would make it difficult to provide adequate shear transfer via shear keys in element joints.

Small chamfers have been considered in all tubes since the forces carried through the wall-to-slab connections points are significant.

A transverse slope of the roadway of 2.0% has been assumed in tubes with road traffic. Ballast concrete is assumed to have the same slope.

A pavement of 100 mm (constant thickness) on top of ballast concrete (not considered in the uplift stability) has been assumed.

It has been assumed that the vertical clearance requirement applies from edge of barrier to edge of barrier.

It has further been assumed that +/- 0.104m shall be allowed to account for differences in thickness of the ballast concrete along the tunnel length due to deviation between the piece-wise straight element alignment and the vertically curved road alignment.

The thickness of the ballast concrete in the MUP tubes has been selected so the top surface corresponds with the average top surface of the ballast concrete in the road tubes. This allows for easy emergency egress from the roadway tube to the MUP tube.

A thickness of ballast concrete of in the order of 900 mm to 1 m has been targeted to allow for installation of drainage pipes and similar items in the ballast concrete.

B.4.1 Type 1, reinforced concrete with post tensioning

The overall dimensions of the concrete section with post tensioning is 47.1m x 10.2m. The thickness of top and bottom slabs is 1425mm, the outer walls is 1400mm and the inner walls are between 800 mm and 900mm. There is a membrane on the bottom slab that can be either a rigid plastic membrane or steel membrane. A sprayed on membrane is assumed for the walls and top slab. The top slab has 75 mm of protection concrete.

Top and bottom slabs have three - 19 x 0.6" posttensioning strands (6819, 2660mm²) cables per metre,. The outer walls have one posttensioning cable per metre of wall. The total amount of post tensioning cables is 6.2 ton/metre of tunnel.

B.4.2 Type 2, steel-concrete-steel sandwich type, SCS

The overall dimensions of the steel-concrete-steel section is essentially the same as the Type 1 option. The exterior surfaces of the steel shell are protected by sacrificial zinc / aluminium anodes on the side walls, by grout on the bottom slab, and protection concrete (150mm) on the top slab. The outer and inner skin plates are of steel. The preliminary steel thickness is between 8 to 25mm for the inner and outer skin plates, the diaphragm 8 mm and shear plates 8-20mm.

Appendix C Deas Slough Bridge and River Road Overpass Concept Design

DRAFT

MEMO

TITLE GMC Bridge Options Associated with Immersed
Tube Tunnel (ITT) - DRAFT

DATE 29 November 2019

TO Darryl Matson, Don Bergman

COPY Anna Lemaire, Anne-Marie Langlois

FROM Hendrik Westerink

PROJECT NO A127810

ADDRESS COWI North America Ltd
138 13th Street East
Suite 400
North Vancouver, BC V7L 0E5
Canada

TEL +1 604 986 1222

FAX +1 604 986 1302

WWW cowi.com

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1 Introduction

In July 2019, COWI North America Ltd. and Stantec (CST) were awarded an assignment to provide as & when technical services to the BC Ministry of Transportation and Infrastructure (Ministry) for the George Massey Crossing Project. The assignment was to provide technical support in response to questions asked by the Ministry (or the Mayors Task Force through the Ministry).

The purpose of this memo is to document the conceptual work completed for the assessment of the Deas Slough Bridge and River Road Overpass associated with the Immersed Tube Tunnel (ITT) option for the Fraser River crossing of the George Massey Crossing Project.

The options considered and the key considerations in determining the preferred layout and concept for the bridge options are discussed. The work on the bridge options is based upon input secured from the Province.

2 Deas Slough Bridge

The immersed tube tunnel returns to existing grade on Deas Island south of the Fraser River and requires a bridge to span Deas Slough at the south entrance to the tunnel. The bridge begins at the south end of the open tunnel ramp and extends 310 m to the south bank of Deas Slough. A conceptual drawing of the preferred structural option selected for the Deas Slough Bridge is shown on drawing IT910 in Appendix A – Deas Slough Bridge and River Road Overpass Drawings and in Figure 1 below. The seven-span bridge comprises a cast-in-place concrete substructure. Steel girders were selected for the 70 m governing span length and act compositely with a concrete deck.

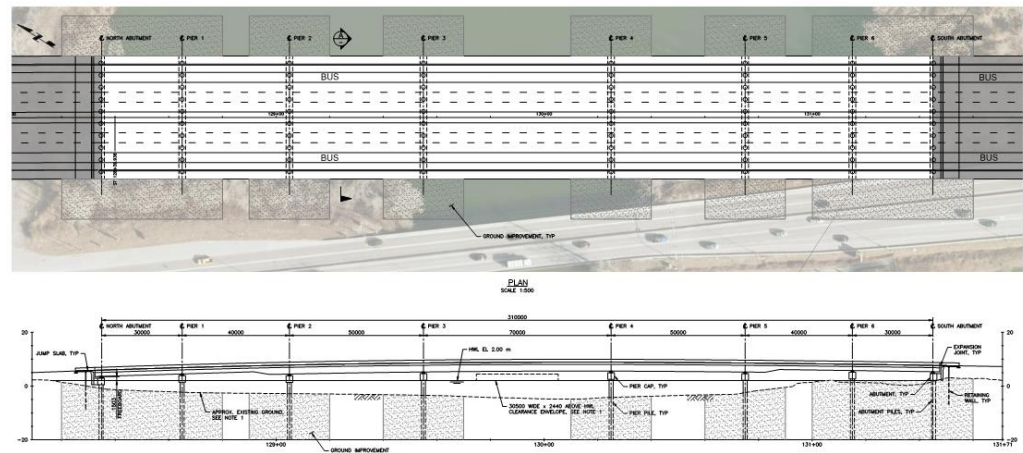


Figure 1 – Conceptual Deas Slough Bridge

Initially, a three-span, a five-span and a seven-span bridge option were considered for spanning Deas Slough. Each of these options requires in-water work in Deas Slough. Additionally, each of these options is constrained by the elevation of the roadway at the south end of the ITT south open tunnel ramp, which results in a limited freeboard between the Deas Slough high-water level and the underside of the superstructure.

The seven-span bridge option shown in Figure 1 was selected as it provides the maximum freeboard to the underside of the structure. To further increase the freeboard, the girder depth was reduced for the shortest end spans of the bridge.

The bridge option presented is conceptual and requires additional confirmation of the following items at a future stage of the project:

- > The Deas Slough navigation channel and existing bed level of Deas Slough are based on original design drawings for the existing bridge over Deas Slough. Additional verification may be required to confirm these important parameters.
- > Verification of substructure sizing and ground improvement extents will be required at a future stage.
- > The underside of the steel girder superstructure is approximately 1.5 m above the high-water level in Deas Slough. The limited freeboard to the saltwater in Deas Slough will merit further verification of the durability of the girders, including the potential need to paint the steel superstructure.

3 River Road Overpass

As the highway alignment for the immersed tube tunnel options is near existing grade at the intersection with River Road, the Ministry requested that CST consider the possibility of adding an overpass at River Road to allow east/west traffic to pass over Highway 99. The overpass is not part of the GMC project and could be completed by others. A conceptual drawing of a possible structural option for the River Road Overpass is shown on drawing IT911 in Appendix A – Deas Slough Bridge and River Road Overpass Drawings and in Figure 2 below. The two-span bridge comprises a cast-in-place concrete substructure. For the maximum 36 m span length, steel or concrete girders could be selected and will act compositely with a concrete deck.

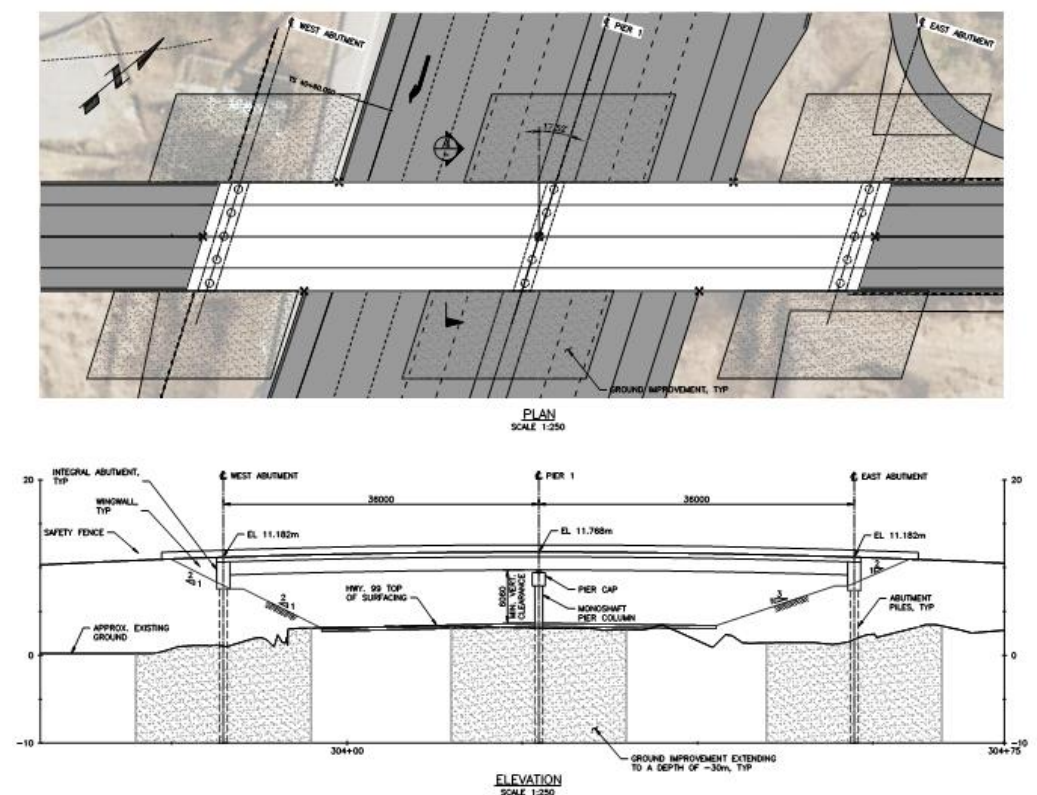


Figure 2 – Conceptual River Road Overpass

Initially, the two-span bridge across Highway 99 was evaluated against a single 72 m clear span bridge. The two-span bridge was selected to avoid the additional superstructure depth and bridge cost associated with the single clear span option. A

clear span structure could be considered in the future if warranted by the complexity of placing a pier near existing traffic on Highway 99.

Additional features of the two-span bridge include perched abutments with embankments leading down to Highway 99 to promote an open feeling when passing under the structure and integral abutments to reduce the future maintenance costs associated with bearings and expansion joints.

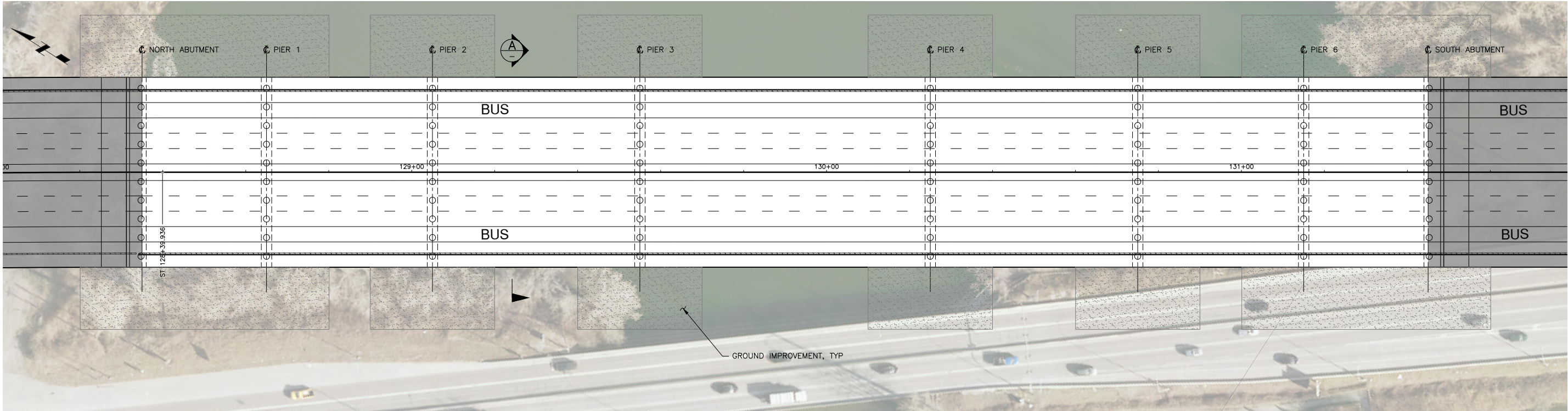
The bridge option presented is conceptual and requires additional confirmation of the following items at a future stage of the project:

- > The minimum vertical clearance provided above Highway 99 is 6060 mm. Future optimization of the River Road vertical alignment may be possible to reduce this clearance to 5000 mm and reduce the length of approach for the River Road Overpass.
- > Verification of substructure sizing and ground improvement extents will be required at a future stage.

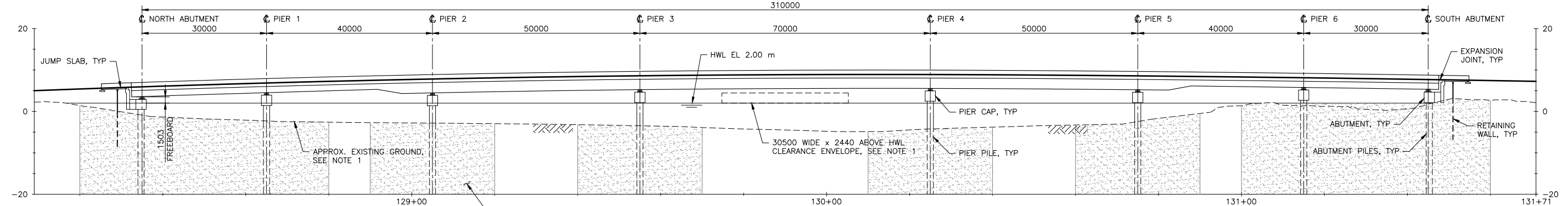
4 Conclusions

The selected seven-span bridge for the Deas Slough Bridge and two-span bridge for the River Road Overpass represent feasible bridge options for the George Massey Crossing immersed tube tunnel option. Additional work at future project stages will be required to further refine and develop these bridge concepts.

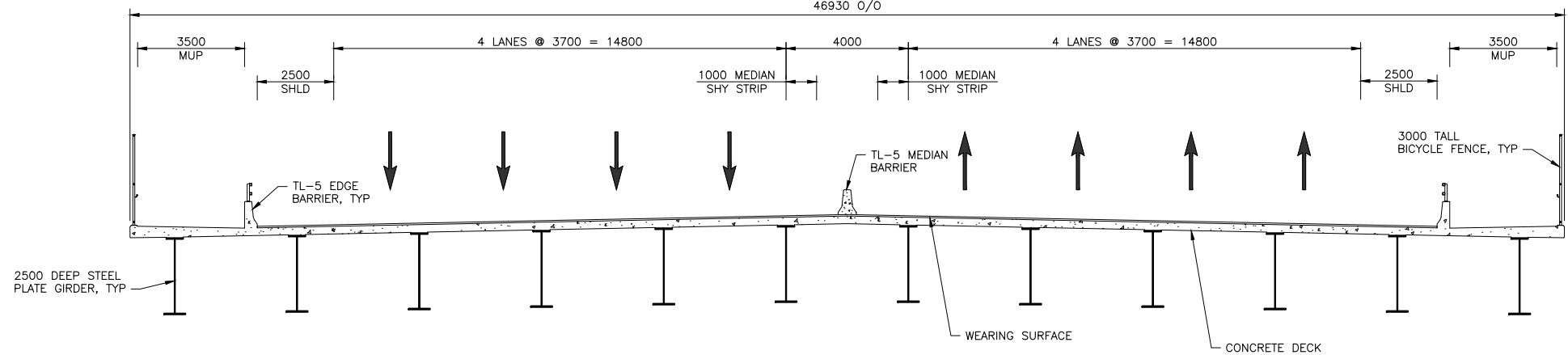
Appendix A – Deas Slough Bridge and River Road Overpass Drawings



PLAN
SCALE 1:500



ELEVATION
SCALE 1:500



SECTION A-A
SCALE 1:100

NOTES:
1. EXISTING DEAS SLOUGH RIVER BED LEVELS AND NAVIGATION CLEARANCE ENVELOPE BASED ON ORIGINAL BRIDGE DESIGN DRAWINGS. RIVER BED LEVELS AND REQUIRED NAVIGATION CLEARANCE TO BE CONFIRMED AT LATER PROJECT STAGES.

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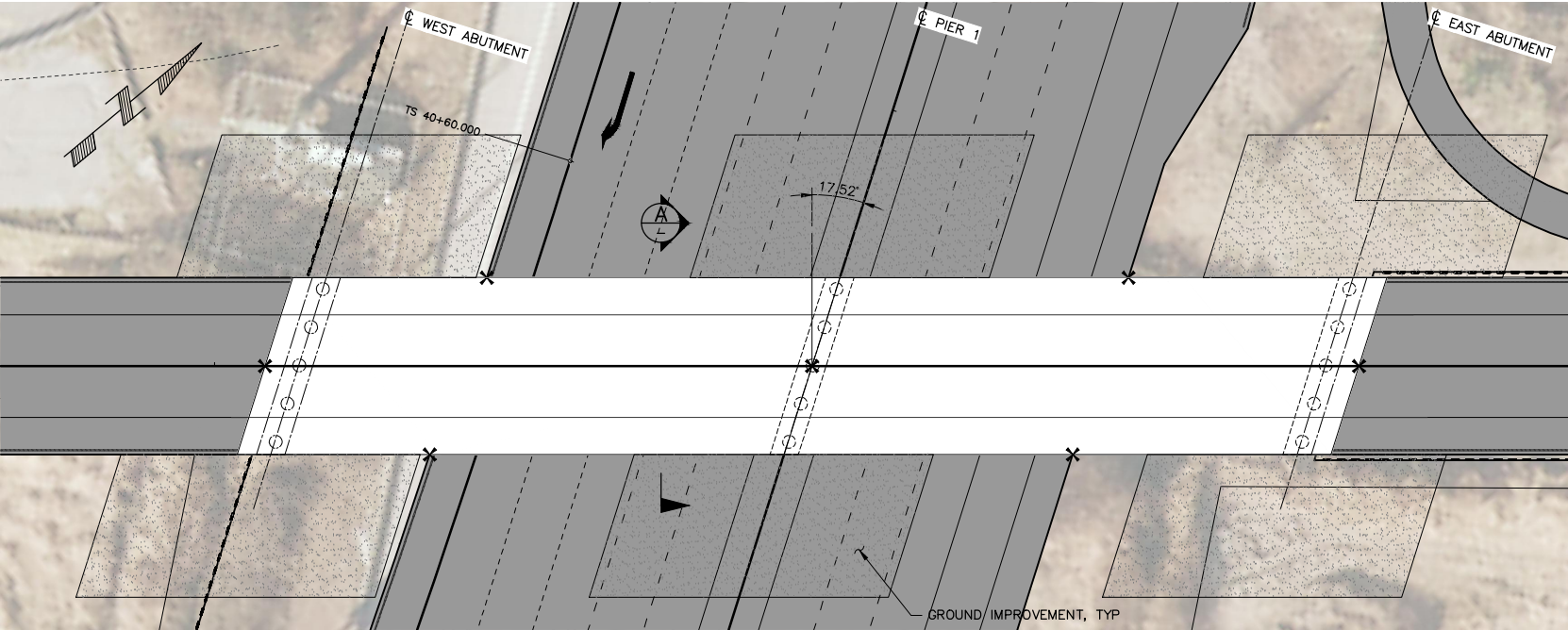
REVISIONS

BRITISH COLUMBIA Ministry of Transportation & Infrastructure South Coast Region

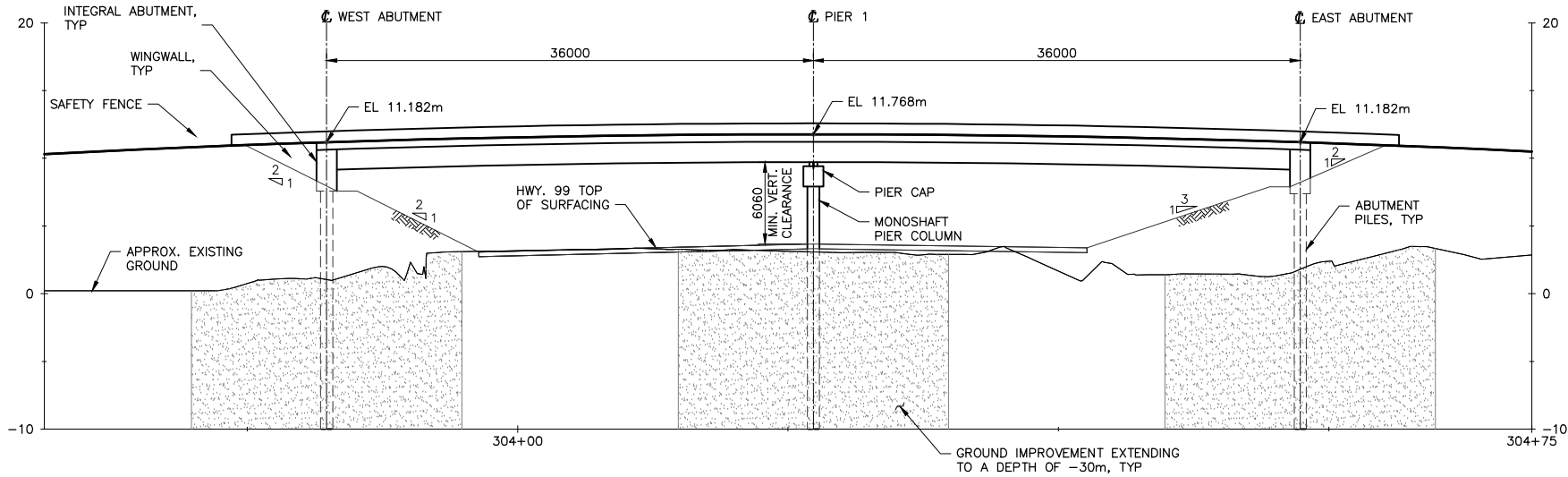
LOWER MAINLAND HIGHWAY DISTRICT
HIGHWAY 99
**MASSEY CROSSING – IMMERSED TUNNEL
DEAS SLOUGH OVERPASS – GENERAL ARRANGEMENT**

PREPARED UNDER THE DIRECTION OF		DESIGNED		DATE 2019-11-15	
CHECKED		DATE		DATE 2019-11-15	
DRAWN		CRBL/CRLS		DATE 2019-11-15	
ENGINEER OF RECORD		SCALE		AS SHOWN	
DATE		NEGATIVE No.			
FILE No.		PROJECT No.		REG.	
1070-20		15CS1036		1	
				DRAWING No.	
				IT910	

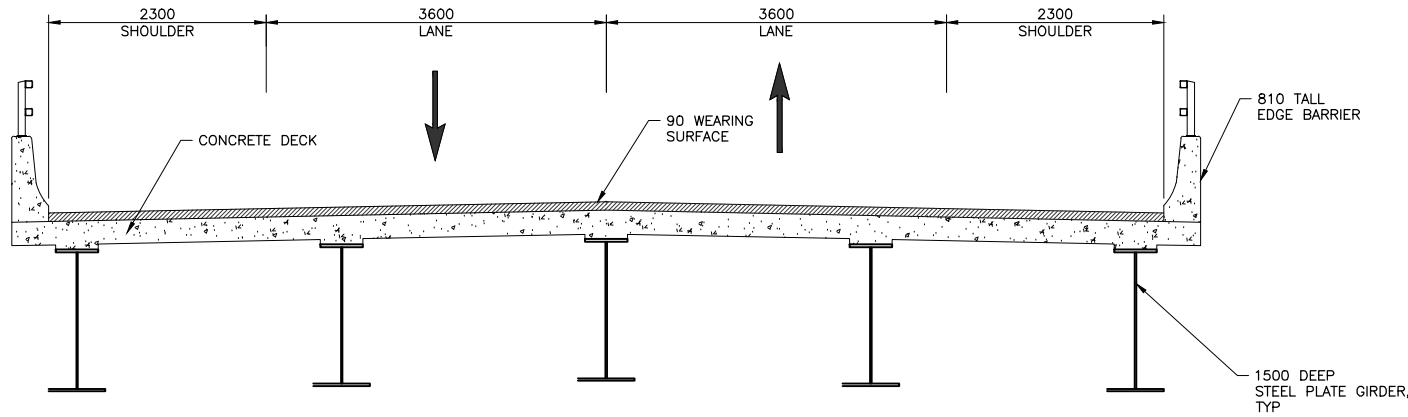
CANCEL PRINTS BEARING PREVIOUS LETTER



PLAN
SCALE 1:250





ELEVATION
SCALE 1:250



SECTION A-A
SCALE 1:40


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BRITISH COLUMBIA

Ministry of Transportation & Infrastructure
South Coast Region

LOWER MAINLAND HIGHWAY DISTRICT
HIGHWAY 99
MASSEY CROSSING – IMMERSSED TUNNEL
RIVER ROAD OVERPASS – GENERAL ARRANGEMENT

PREPARED UNDER THE DIRECTION OF		DESIGNED – DATE 2019-11-15	
CHECKED – DATE		DRAWN – DATE 2019-11-15	
ENGINEER OF RECORD		SCALE AS SHOWN	
DATE		NEGATIVE No.	
FILE No. 1070-20	PROJECT No. 15CS1036	REG. 1	DRAWING No. IT911